Solute Dispersion by Electroosmotic Flow in Nonuniform Microfluidic Channels

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Introduction

Dispersion is a phenomenon that determines the resolution of several types of liquid phase chromatography, and is an important component of overall transport through electrokinetic flow systems. The severe dispersion of solute as it travels through a U-turn, for example, has attracted recent attention for this reason [1]. In "ideal" electroosmotic flow through uniform, straight channels (in the limit of thin double layers), solute dispersion is simply due to axial diffusion. However, in straight microfabricated channels, channel nonuniformities may arise due to surface roughness (e.g., due to etching or powderblasting fabrication methods [2]), or imperfections (e.g., etch pits, waviness due to poor resist adhesion, or imperfect bonding of channel lids). Other nonuniformities may be intentional, e.g., engineered post arrays for capillary electrochromatography. In this work, we measure dispersion in several types of nonuniform channels, and report their geometric Taylor-Aris dispersion coefficients α_o. The dispersion coefficient relates the effective diffusion coefficient $D_{eff} = D_{12}(1 + \alpha_o Pe^2)$, to the binary diffusion coefficient, D_{12} as a function of the Peclet number [3,4].

Measurements

Measurements are performed in glass channels using a custom-built fluorescence imaging apparatus. The two types of perturbations studied are (a) well-defined perturbations (square-wave and sawtooth) of various wavelengths and amplitudes (Fig. 1), and (b) fine-scale random roughness introduced by a powderblasting channel fabrication method (Fig. 2). Samples of Rhodamine-110 dye (in a 50:50 solution of 20mM phosphate buffer and acetonitrile) are injected into several parallel channels of different waviness, as shown in Fig. 3. As the samples move through the channels, they assume a Gaussian profile of width $\sigma^2 = 2D_{eff}t + \sigma_o^2$, where t is time and σ_o is the initial plug width. Gaussian fits to profiles in a single channel (Fig. 4) give values of σ^2 at various times; plotting this versus time gives a straight line of slope $2D_{eff}$.

Results

Measurements of D_{12} (with no flow, Pe = 0) were repeatable to within 2%. Performing the experiment at several Peclet numbers (varied by increasing the applied electric field), provides D_{eff} versus Pe^2, which gives the dispersion coefficient α_o for a given geometry. Results for several geometries are shown in Fig. 5. The largest dispersion coefficient is $1.6*10^{-3}$ (for the large perturbation channels). Extending these results to large molecules of low diffusivity, it is possible (at, say, Pe=1000) to reach effective diffusivities which are more than 2.5 times the binary diffusion coefficient.

References

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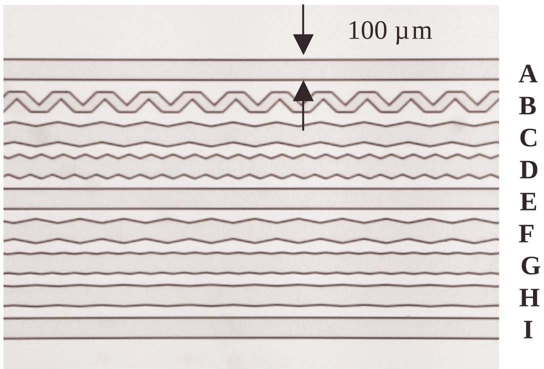

Fig. 1: Picture of the sawtooth-shaped channels (depth 13 µm) that were studied. Channels have perturbations of various amplitudes (0, 3 or 10 µm) and wavelengths (100 or 200 µm).

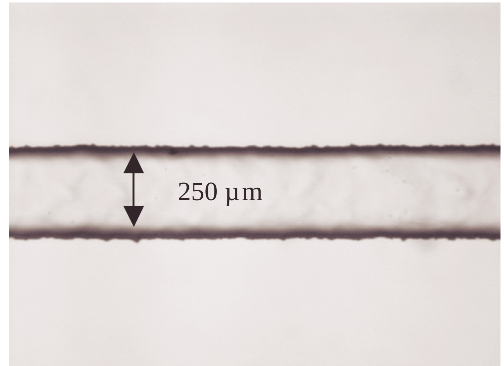

Fig. 2: Picture of a microfluidic channel fabricated using powderblasting with 9 µm particles giving a channel roughness of approx. 1 µm.

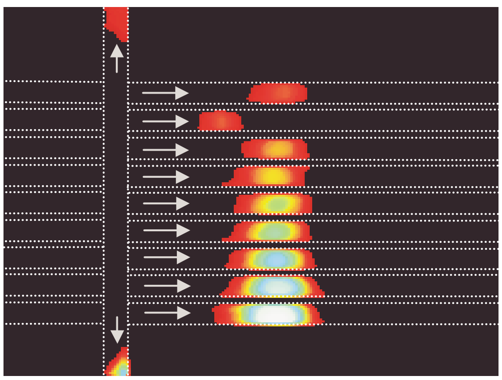

Fig. 3: Injection part of the chip shown in Fig. 1 showing injected plugs of fluorescent dye used for characterization of the dispersion

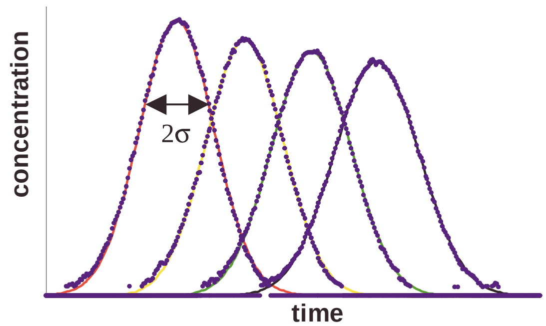

Fig. 4: Measured concentration profiles at various times fitted by Gaussian curves giving the variation of the plug variances with time.

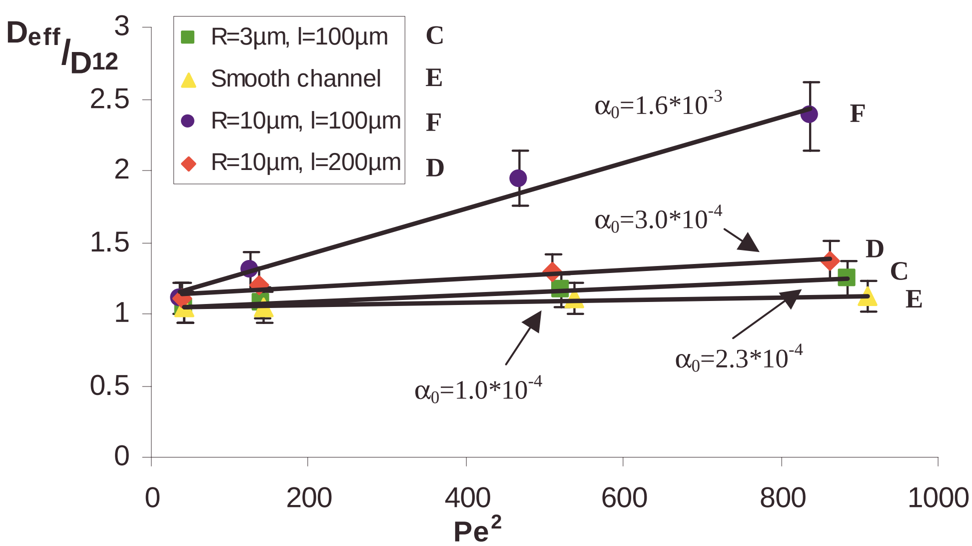

Fig. 5: Graph showing the measured ratio of the effective diffusivity D_{eff} over the binary diffusion coefficient D_{12} at various Pe^2 numbers for channels C,D,E,F from Fig.1. It is clear from this graph that the dispersion, given by the curve slopes, is higher for rougher channels. The effect of increasing perturbation amplitude and decreasing wavelength appears to be more than proportional.